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Small-scale turbulence and the problems of studying the ecosystem of Lake Baikala

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Small-scale turbulence and the problems of studying the ecosystem of Lake Baikal

by V.A. Verkhozina, Yu.S. Kusner, V.A. Safarova and N.D. Sudakova

(Limnological Institute of the Siberian Department of the USSR Academy of Sciences, Irkutsk)

When describing, simulating or studying the stability of ecosystems, specifically lacustrine ecosystems, it is assumed that the mathematical structure of the equations is analogous to the structure of the equations of the chemical kinetics, i.e. the temporary characteristics of the concentrations of the products are determined by the local concentrations of the substrates and products. However, such an assumption may turn out to be qualitatively inconsistent with the experiment if the spatial heterogeneities of the components of the ecosystem are of a smaller scale or comparable to its characteristic values [1, 2]. In this case, the stability of ecosystems is greatly determined by the non-linear interaction of the hydrodynamic movement and this or that population, and cannot be researched by studying the "mean values" of the population levels [1]. When measuring certain ecosystem parameters, the value of the scales of spatial heterogeneities is apparently required for objective analysis

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of the values derived in a discrete experiment.

In this particular paper, we have shown through measurement and analysis of the spatial heterogeneity in the distribution of chemoorganotrophic bacteria that the above situation, which, generally speaking, is a unique one for "ordinary" lakes, is currently observed in Lake Baikal. A low rate of reproduction of the typical biological species and a fairly high rate of turbulent mixing dictate the characteristic scale of the "patchy" structure of the spatial distribution of the species (called patchiness [3]), which is smaller than would be expected for the given size of the lake.

Proceeding from simple physical considerations, it becomes clear that fairly small organisms such as particles of phytoplankton [1, 3] or, in the the given case, microorganisms with a Brownian movement rate exceeding the rate of gravitational settling for example, should move like a passive molecular suspension in the water. Simple calculations have shown that the size of such particles should not exceed 10^{-3} cm. This type of movement has been demonstrated, for example, in a laboratory experiment involving the generation of a Langmuir circulation in a vessel containing one of the phytoplankton species [4]. (2)

In order to determine the scales of spatial heterogeneities in the concentration of biological organisms during their interaction with the turbulent movement of the water, it is necessary to establish the type of spectrum of the heterogeneities. Using methods based on the theory of mixtures reacting chemically in a turbulent flow, Denman, Okubo and Platt [5] derived an equation

for the form of the spectrum of fluctuations in the concentration of chlorophyll as a function of wave number. The spectrum was derived as the solution of the hydrodynamic equation for the region of wave numbers, which corresponds to the inertial region of turbulent movement where the effects of molecular diffusion can be disregarded. This spectrum is qualitatively different from the one derived earlier by Denman and Platt [6] using methods of dimensional analysis, i.e. its maximum is observed at a wave number of $K_m = (2/5)^{3/2}(r\varepsilon^{-1/3})^{3/2} = (2/5)^{3/2}K_c \simeq 0.25\ K_c$ (1) where ε denotes the rate of dissipation of turbulent energy in a mass unit of liquid, r - the parameter of exponential growth in the concentration of phytoplankton, and K_c - the characteristic wave number, i.e. $K_c = (r\varepsilon^{-1/3})^{3/2}$. (2)
The spectrum obtained by Denman and Platt [6] increases monotonically in proportion to K^{-1} when $K \ll K_c$. It was assumed [5] that the given difference arose because the convective effects (i.e. the components containing ε) were disregarded during dimensional analysis in the $K \ll K_c$ region, as compared with the effect of biomass reproduction (i.e. the components containing r); this is precisely why the spectrum did not depend on ε when $K \ll K_c$.

We shall now show that the type of spectrum of fluctuations in chlorophyll (and any other nonconservative particles) can be obtained without any simplified assumptions by the method of dimensional analysis of a developed turbulent movement [7]. It is sufficient to use the well-known formula for the rate of particle divergence over the distance $\lambda \equiv k^{-1}$ in the inertial region of turbulent diffusion, $\frac{d\lambda}{dt} \equiv v_\lambda \simeq (\varepsilon\lambda)^{1/3} = (\varepsilon/K)^{1/3}$ (3)

Let us regard the problem as two-dimensional, i.e. the chlorophyll distributed and diffused over the surface of the water. Proceeding from the apparent indissolubility correlation for "conservative" particles, we get

$$\beta\lambda^2 = \beta_0\lambda_0^2 = const \tag{4}$$

where β and β_0 are the current and initial concentration of chlorophyll. Thus,

$$\frac{d\beta}{dt} = -\frac{2\beta}{\lambda}\cdot\frac{d\lambda}{dt} \tag{5}$$

If the chlorophyll reproduces at a rate of r $(\beta-\beta')$, where β' denotes the concentration of chlorophyll at which it ceases to reproduce ("equilibrium" concentration), then equation (5) changes in an apparent manner, i.e.

$$\frac{d\beta}{dt} = -\frac{2\beta}{\lambda}\frac{d\lambda}{dt} + r(\beta-\beta') \tag{6}$$

or, if we switch to the wave numbers and use equation (3)

$$\frac{d\beta}{dK}\frac{dK}{dt} = \varepsilon^{1/3}K^{5/3}\frac{d\beta}{dK} = -\beta\left[2K\left(\frac{\varepsilon}{K}\right)^{1/3} - \left(1-\frac{\beta'}{\beta}\right)r\right] \tag{7}$$

and from equation (7) it is obvious that with $\beta \gg \beta'$, the spectrum in question will reach its maximum at $K = K_m$:

$$-2K_m(\varepsilon/K_m)^{1/3} + r = 0$$
$$K_m = (1/2\, r\varepsilon^{-1/3})^{3/2} = (2{,}515)^{3/2}K_c \tag{8}$$

i.e. at practically the same value as in equation (2). With $\beta \ll \beta'$, the maximum degenerates, and the spectrum becomes monotone, approaching the spectrum of the conservative admixture. If we integrate equation (7) with the initial wave number of the source K_0, we end up with

$$(\beta/\beta_0) = \left[(K_0/K_c)^2/(K/K_c)^2\right]\cdot\exp\left[3(K_c/K_0)^{2/3}\right]\cdot\exp\left[-3(K_c/K)^{2/3}\right] \tag{9}$$

The form of the spectrum with $(K_0/K_c)=1$ and its comparison with the spectrum in ref. 5 with the same parameters are given in

Fig. 1. As we can see, the distribution (9) is qualitatively congruent with the spectrum in ref. 5. The insignificant quantitative differences lie in a more gently sloping maximum and a sharper decrease when $K \gg K_c$ and $K \ll K_c$. Consequently, dimensional analysis permits us to derive the spectrum of nonconservative particles consecutively. However, we should take into account that the condition $\beta \gg \beta'$, used to determine the scale of heterogeneities (8), may not hold true in a natural environment. For example, in early ocean experiments [3], the spectrum of chlorophyll was measured, and it was found to coincide with the spectrum of the passive admixture. No maximum was observed in the chlorophyll spectrum measured in Lake Tahoe, USA; instead, a clearly defined break was detected in the spectrum with wave numbers in the neighbourhood of K_m, though the spectrum did differ from that of the passive admixture [8]. (4)

In the investigations on Lake Baikal, we measured the distribution of chemoorganotrophic bacteria around a stationary source, the sewer pipe of the Baikal pulp and paper mill. The measurements were carried out in July 1985 and 1986. The average July concentration of these bacteria over a number of years for the given area of Lake Baikal is 10^2 cm^{-3}, while their concentration in the discharge is at least 10^4 cm^{-3}, and the fact that the concentration being measured was much greater than the background concentration made it much easier to carry out the measurements. The added advantage when measuring the distribution of bacteria is that their r value is greater than for phytoplankton, which results in smaller, more easily detectable values of the characteristic scales

of patchiness $(K_m)^{-1}$, as we can clearly see from equation (8). It should be said that the measured distributions of microorganisms have been successfully used to study stratification and currents in the oceans [9].

Water samples in the vicinity of the Baikal pulp and paper mill were taken from the surface on a grid of 14 km west and 14 km east from the point of drainage at 2 km intervals, and 4 km towards the middle of the lake at 0.5 km intervals. The samples were grown on beef-extract agar to determine the numbers of chemoorganotrophic bacteria. Analysis of the material and plotting of the isoline graphs of distribution of bacteria were carried out by the method of plotting for functions tabulated on a rectangular nonuniform grid in the Cartesian system of coordinates with smooth fulfilment of the functions [10]. Fulfilment of the grid function within the rectangles was carried out with the help of bicubic polynomials, the results of this type of fulfilment being smooth within all the regions of approximation. The program of isoline plotting is written in FORTRAN.

The distributions obtained are shown in Fig. 2a. The distribution of chemoorganotrophic bacteria differs greatly from the distributions of the passive admixture, for example nitrates, the distributions of which were measured at the same time in the same area (see fig. 2b). The concentration of nitrates was determined by Griess' method, and the isolines were plotted by the method described above. The obvious differences in the scales and nature of the distributions indicate that the derived distributions of bacteria cannot be attributed to the distribution of their

chemical substrates which are passive admixtures. At the same time, we can see from equation (8) that for $\varepsilon \simeq 10^{-7}+10^{-9}$ m^2/s^3 [5] (which corresponds to the coefficient of horizontal turbulent diffusion for Lake Baikal $\nu \simeq 1+10^2$ m^2/s) and for $r \simeq 10^{-4} s^{-1}$, the scale of spatial distribution of microorganisms is $(K_m)^{-1} \simeq$ 1.5+0.15 km, and, as we can see from the comparison with Fig. 2a, this correlates quite well with the scale of spatial heterogeneities observed in the experiment. A more detailed comparison with theoretical spectra on this grid of measurements would be difficult and senseless.

Thus, the above experimental results and their analysis point to the presence of signficant spatial heterogeneities in the ecosystem of Lake Baikal; as in the seas and oceans, they are related to the significant effect of the hydrodynamic parameters on the structure of the ecosystem [1, 3, 5, 6]. For example, according to the measurements [11], the scales of the heterogeneities in the distribution of the zooplankton and phytoplankton differ substantially, which can result in their spatial separation; however, we should take into account that zooplankton distribution is apparently not always directly related to the hydrodynamic picture [12]. In any case, such structures differ significantly from the structure of the ecosystems of small lakes, the characteristic dimensions of which are smaller than the spatial heterogeneities.

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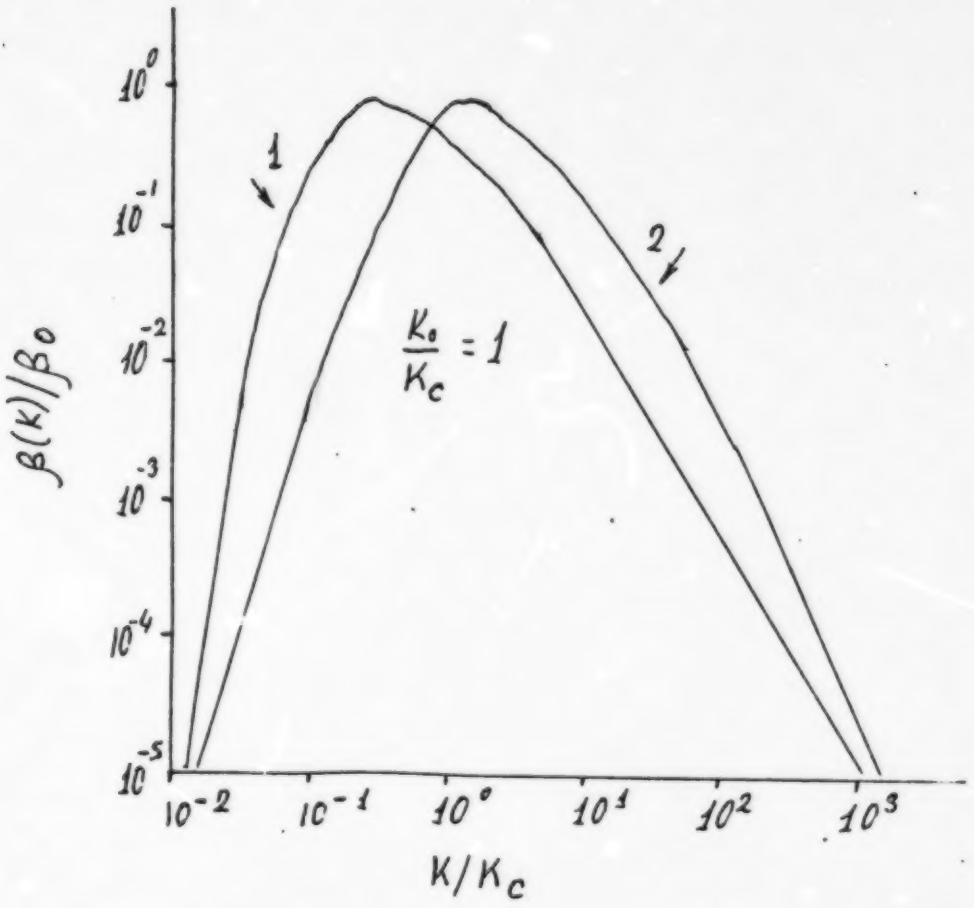
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$\beta(k)/\beta_0$
1
2
$\frac{K_0}{K_c} = 1$
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
K/K_c

Fig. 1.

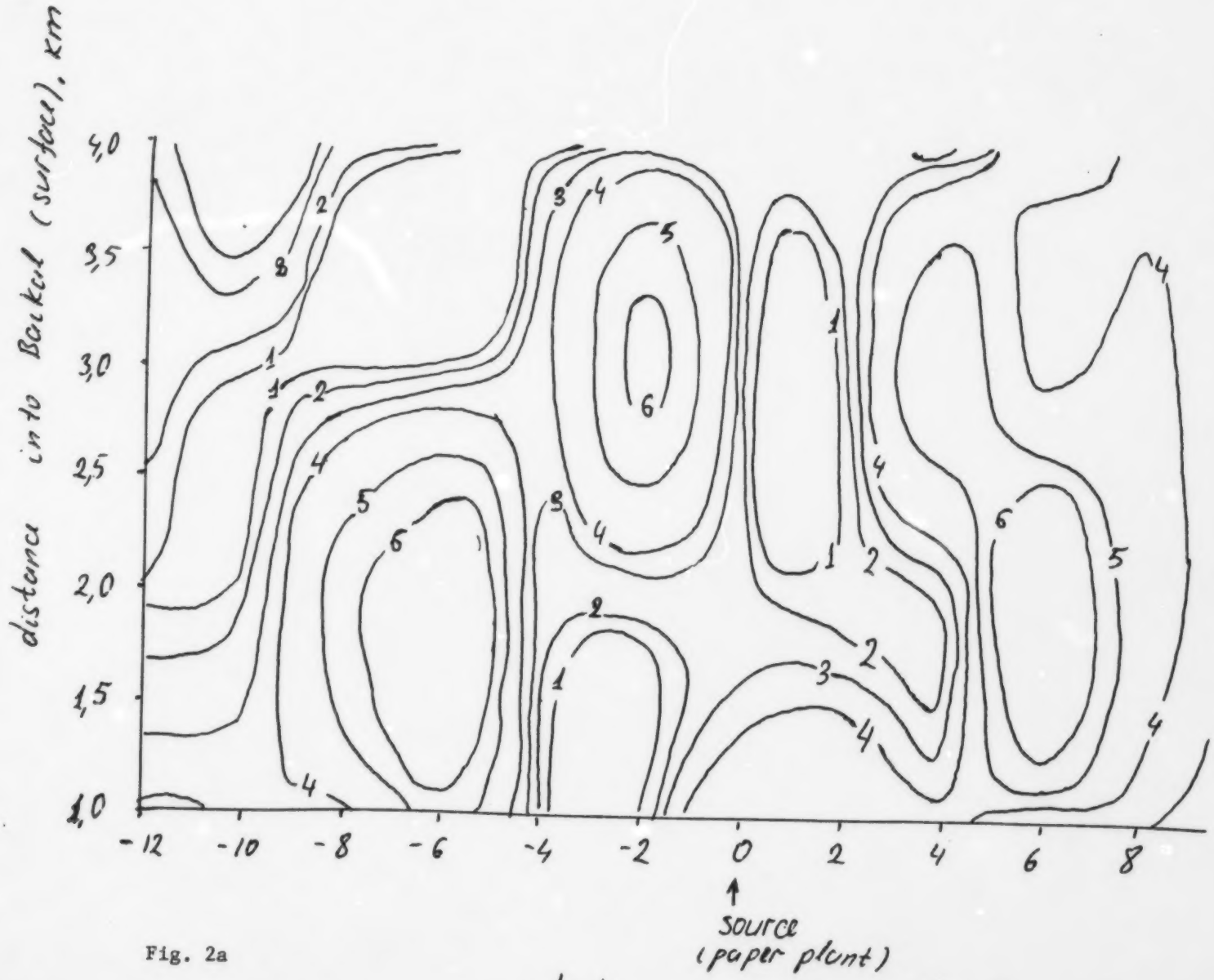
distance into Baikal (surface), km
4,0
3,5
3,0
2,5
2,0
1,5
1,0
-12
-10
-8
-6
-4
-2
0
2
4
6
8
source
(paper plant)
distanse along land, km

Fig. 2a

Fig 2a

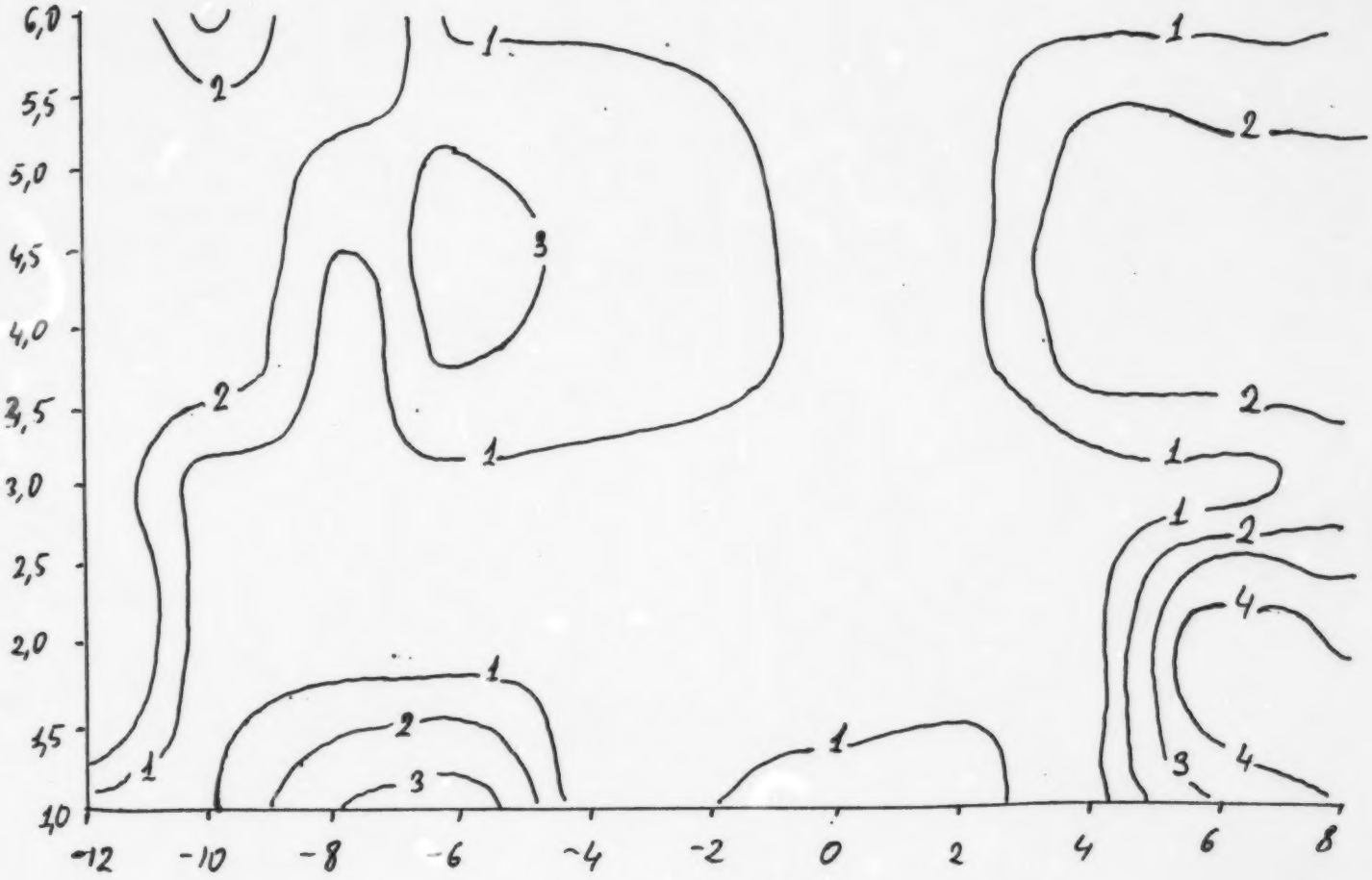
dist. into vertical (surface), km.
6,0
5,5
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
-12
-10
-8
-6
-4
-2
0
2
4
6
8
sourse
(paper plant)
distance along land, km

Fig. 2b

Fig

FIGURE CAPTIONS

Fig.1 Distribution spectra of concentration of non-conservative admixtures in inertial subrange of turbulence

1 - spectrum in work [5];
2 - spectrum in this work

Fig.2 Measured distributions of admixtures in Lake Baikal, region of palp-and-paper plant, July, 1985, distance on axis in km.

2a - Distribution of heterotrophyc bacteria. Lines of concentration levels, cm^{-3}; 1 - 0 ÷ 100; 2 - 100 ÷ 500; 3 - 500 - 1000; 4 - 1000 ÷ 3000; 5 - 3000 ÷ 6000; 6 - 5000 ÷ 7000

2b - Distribution of nitrites. Lines of concentration levels, (mg/L). 1 - $10^{-4} \div 5 \cdot 10^{-4}$; 2 - $5 \cdot 10^{-4} \div 10^{-3}$; 3 - $10^{-3} \div 10^{-2}$; 4 - $10^{-2} \div 5 \cdot 10^{-2}$

Literature

1. Steele J.H. - Nature, 1974, v 248, N 5443, p. 83
2. Loechle J. - Ecological Modelling, 1987, v. 36, N 3/4, pp. 297 - 314
3. Platt T. - Deep-Sea Res., 1972, v 19, N3, pp. 183-187.
4. Watanabe M., Harashima A. - Ecological Modelling, 1986, v. 31., N 1/4, pp. 175 - 183.
5. Denman K.L., Okubo A., Platt T. - Limnology and Oceanography, 1977, v. 22., N 6, pp. 1033 - 1038.
6. Denman K.L, Platt T. - J. Mar. Res., 1976, v. 34, N2, pp 593 - 601.
7. Landau L.D., Lifchitsh E.M. Gydrodynamics, 3-th ed., Moskaw "Nauka", 1986, 780 p. (in Russian)
8. Powell T.M., Richerson P.J., Dillon T.M., Agel B.A., Dozier B.J., Godden D.A, Myrup L.O. - Science, 1975, v. 189, N4208, pp. 1088 - 1090.
9. Kriss A.E. Microbiological Oceanography. Moskaw, "Nauka", 1976, 266 p. (in Russian)
10. Akima H. - J. ACM., 1970, v. 17, N4, pp 589 - 602.
11. Moskos D.B., Boyd O.M. - Science, 1979, v. 204, N 4388, pp. 62 - 64.
12. Yoshioka P.M., Owen G.P., Pesante D. - J. Plankton Res., 1985, v. 7., N6, pp. 733 - 751.

SMALL-SCALE TURBULENCE AND BACTERIAPLANKTON PATCHINESS ON LAKE BAIKAL.

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A B S T R A C T

It is shown that bacteriaplankton distribution on lake Baikal is sufficiently controlled by turbulence. Characteristic dimension of patchy distribution - $l = 1 \div 2$ km - is coinsidied well with theoretical formula:

$$l = (K_m)^{-1} = \sqrt{\varepsilon / 2 r^3}$$

where ε - energy dissipation in locally isotropic turbulence,

K_m - wave number corresponding the maximum of turbulence spectra,

r - reproduction speed of bacteriaplankton.

The formula was dedused in the work for inertial subrange of turbulence only from hypoteses of similarity. Due to large dimensions of Lake Baikal in comparation with dimension of patching its ecosystem becomes similar to one of the ocean.

For Kennet Denman
With the best regards.
Ju. S. Kusner.
V. A. Verhotina
lak Baikal
27.02.86